

# Measurement of the $\beta - \nu$ Correlation in Laser Trapped $^{21}\text{Na}$

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Laser-trapped radioactive atoms provide an ideal source of beta activity for precise measurements of kinematic correlations. Atoms in a magneto-optical trap (MOT) are isotopically pure and confined to a small volume ( $1 \text{ mm}^3$ ). Due to their low temperature ( $100 \text{ } \mu\text{K}$ ) and density ( $10^{11} \text{ atoms/cm}^3$ ), the atoms decay nearly at rest and the daughter products emerge without scattering. Precise measurements of beta decay correlations test for the presence of new quark-lepton couplings predicted by some beyond-Standard-Model theories.

Our previous measurement of the beta-neutrino correlation in  $^{21}\text{Na}$  found a correlation coefficient  $a_{\beta\nu} = 0.5243(91)$ , compared to the Standard Model prediction  $a_{\beta\nu} = 0.5580(30)$  [1, 2]. This  $3.6\sigma$  difference may be caused by  $^{21}\text{Na}$  dimer molecules in the system. If  $^{21}\text{Na}$  beta decays while bound to another atom, the momentum of the outgoing recoil ion can be changed as it scatters off of the strong potential of its molecular partner. Previous measurements of the beta-neutrino correlation have been susceptible to this perturbation [3].

The creation of molecules in the trap is a result of light assisted collisions between atoms. Specifically, dimers are formed by a photoassociation (PA) process in which two ground state atoms are resonantly excited by the trap lasers to an excited, attractive state of  $^{21}\text{Na}_2$ , which then decays to a cold, stable, ground molecular state. These molecules are out of resonance with the MOT beams, but they are still *magnetically* trapped by the quadrupole magnetic fields of the MOT. Dimers are detected via a similar PA process in which two photons are absorbed, driving the molecule to an excited, autoionizing state, creating an electron and ionized dimer. The dimer ions are detected in a coincident time-of-flight (TOF) spectrum in our trap apparatus (see Fig.1). Our observed rate of dimer formation in  $^{23}\text{Na}$  is consistent with cold PA studies in other alkali atoms, and at a level which could perturb  $a_{\beta\nu}$  by 5-6%.

Molecule formation can be suppressed using a Dark MOT configuration [4]. In sodium trapping the bright and dark states are the  $F=2$  and  $F=1$  hyperfine levels of the  $3S_{1/2}$  state, respectively. MOT beams are resonant with the  $F = 2 \rightarrow 3P_{1/2}F' = 3$  cycling transition, so the dark hyperfine level will not interact with the trapping beams. However, because spontaneous Raman scattering eventually optically pumps atoms from the bright to dark state, a standard (Bright) MOT repumps atoms back into the cycling transition by mixing in light resonant with  $F = 1 \rightarrow F' = 2$  transition. In the

Dark MOT this repumping light is blocked at the center of the trap. Only when atoms reach the outer region of the trap are they pumped back into the cycling transition and consequently pushed back to the center of the trap. Because atoms reside in the  $F=1$  state, light-assisted collisions of excited state ( $3P_{1/2}$ ) atoms, and thus molecular formation, is suppressed. Using a dark MOT, we have suppressed the molecule formation rate

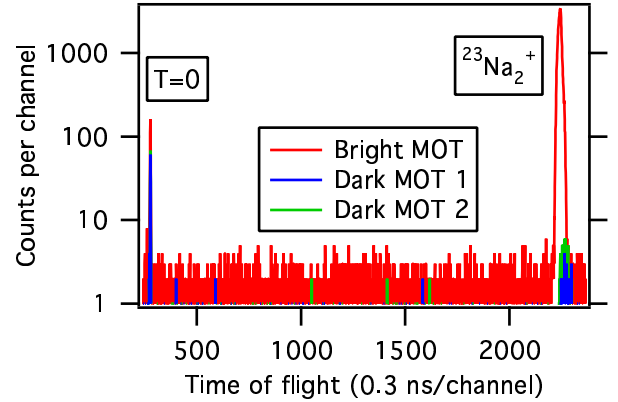


FIG. 1: Suppression of  $^{23}\text{Na}$  Dimers in a Dark MOT. Data from a bright MOT and dark MOTs with the same atom number are shown. The number of detected molecules is greatly suppressed with the dark MOT.

by a factor of 700 compared to the bright MOT (Fig.1).

We are currently working on oven and target design to improve our  $^{21}\text{Na}$  production. We have tested different target configurations (including metallic Mg) and a different oven design with more a uniform temperature profile. We conclude from these tests that the presence of a “carburetor” chamber within the oven is important. This chamber is an expanded region of the oven, free from target material. This space allows the  $^{21}\text{Na}$  atoms to rethermalize and acquire an exit velocity vector directed along the narrow collimation tubes to exit the oven. Once this target testing is complete, we will repeat our measurement of  $a_{\beta\nu}$  using the Dark MOT, to determine what role (if any) dimers played in our earlier measurement. We will measure  $a_{\beta\nu}$  in high-population MOTs in both the bright and dark configuration to search for this systematic effect.

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